GR 99 P 8082

Abstract

Device for detecting polarization mode dispersion

Device for detecting polarization mode dispersion of an optical data signal (OS), which has at least one EXOR gate (EXj; j = 1 ... n) together with an averaging device (LPj; j = 1 ... n) for measuring at least one value (AKFj; j = 1 ... n) of the autocorrelation function of a baseband signal (BB) distorted by polarization mode dispersion.

Figure 1

JC18 Rec'd PCT/PTO 27 DEC 2001

FORM PTO-1390 (Modified) (REV 11-2000) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE		ATTORNEY'S DOCKET NUMBER 112740-387
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR 10/019526
INTERNATIONAL APPLICATION NO. **PCT/DE00/01175**	INTERNATIONAL FILING DATE **14 April 2000**	PRIORITY DATE CLAIMED **28 June 1999**

TITLE OF INVENTION
DEVICE FOR DETETING POLARIZATION MODE DISPERSION

APPLICANT(S) FOR DO/EO/US
Reinhold Noe

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include itens (5), (6), (9) and (24) indicated below.
4. ☒ The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
   a. ☒ is attached hereto (required only if not communicated by the International Bureau).
   b. ☐ has been communicated by the International Bureau.
   c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☒ An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. ☒ is attached hereto.
   b. ☐ has been previously submitted under 35 U.S.C. 154(d)(4).
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
   a. ☐ are attached hereto (required only if not communicated by the International Bureau).
   b. ☒ have been communicated by the International Bureau.
   c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   d. ☐ have not been made and will not be made.
8. ☒ An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
10. ☐ An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).
11. ☒ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☒ A copy of the International Search Report (PCT/ISA/210).

Items 13 to 20 below concern document(s) or information included:

13. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.
16. ☐ A **SECOND** or **SUBSEQUENT** preliminary amendment.
17. ☒ A substitute specification.
18. ☐ A change of power of attorney and/or address letter.
19. ☐ A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
20. ☐ A second copy of the published international application under 35 U.S.C. 154(d)(4).
21. ☐ A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
22. ☒ Certificate of Mailing by Express Mail
23. ☐ Other items or information:

JC13 Rec'd PCT/PTO 27 DEC 2001

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR	INTERNATIONAL APPLICATION NO.	ATTORNEY'S DOCKET NUMBER
10/019526	**PCT/DE00/01175**	**112740-387**

24. The following fees are submitted:.

		CALCULATIONS	PTO USE ONLY
BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :			
☐ Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO	**$1040.00**		
☒ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO	**$890.00**		
☐ International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO	**$740.00**		
☐ International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4)	**$710.00**		
☐ International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4)	**$100.00**		
ENTER APPROPRIATE BASIC FEE AMOUNT =		**$890.00**	
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).		**$0.00**	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	15 - 20 =	0	x $18.00	**$0.00**	
Independent claims	1 - 3 =	0	x $84.00	**$0.00**	
Multiple Dependent Claims **(check if applicable).**			☐	**$0.00**	
TOTAL OF ABOVE CALCULATIONS =				**$890.00**	
☐ Applicant claims small entity status. See 37 CFR 1.27). The fees indicated above are reduced by 1/2.				**$0.00**	
SUBTOTAL =				**$890.00**	
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)). +				**$0.00**	
TOTAL NATIONAL FEE =				**$890.00**	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) **(check if applicable).** ☐				**$0.00**	
TOTAL FEES ENCLOSED =				**$890.00**	
				Amount to be: refunded	$
				charged	$

a. ☒ A check in the amount of **$890.00** to cover the above fees is enclosed.

b. ☐ Please charge my Deposit Account No. ________ in the amount of ________ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. **02-1818** A duplicate copy of this sheet is enclosed.

d. ☐ Fees are to be charged to a credit card. **WARNING:** Information on this form may become public. **Credit card information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

William E. Vaughan (Reg. No. 39,056)
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SIGNATURE

William E. Vaughan
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39,056
REGISTRATION NUMBER

December 27, 2001
DATE

BOX PCT

IN THE UNITED STATES ELECTED/DESIGNATED OFFICE
OF THE UNITED STATES PATENT AND TRADEMARK OFFICE
UNDER THE PATENT COOPERATION TREATY-CHAPTER II

PRELIMINARY AMENDMENT

APPLICANTS:	Reinhold Noe	DOCKET NO.:	112740-387
SERIAL NO:		GROUP ART UNIT:	
FILED:		EXAMINER:	
INTERNATIONAL APPLICATION NO::		PCT/DE00/01175	
INTERNATIONAL FILING DATE		14 April 2000	
INVENTION:	DEVICE FOR DETECTING POLARIZATION MODE DISPERSION		

Assistant Commissioner for Patents,
Washington, D.C. 20231

Sir:

Please amend the above-identified International Application before entry into the National stage before the U.S. Patent and Trademark Office under 35 U.S.C. §371 as follows:

In the Specification:

Please replace the Specification of the present application, including the Abstract, with the following Substitute Specification:

SPECIFICATION

TITLE OF THE INVENTION

DEVICE FOR DETECTING POLARIZATION MODE DISPERSION

BACKGROUND OF THE INVENTION

Long optical waveguide transmission links are used in optical transmission technology. Production dictates that the optical waveguides are not completely isotropic, but rather weakly birefringent. The long transmission link results in frequency-dependent polarization transformation, called polarization mode dispersion or polarization dispersion, abbreviated to PMD. Through the change in

the polarization of the optical signal as a function of the optical frequency and, associated therewith, different frequency-dependent delays, this PMD leads to the widening of transmitted pulses. As such, at the receiving end, the identifiability of the pulses is reduced and, as a result, the transmitted data rate is limited. The term "principal states of polarization", referred to as PSP below, designates those two states of polarization which are orthogonal to one another and to a first approximation do not change when the optical frequency changes. In polarization-maintaining optical waveguides, the principal states of polarization coincide with the principal axes; in other words, are horizontal and vertical. In general, however, the principal states of polarization are arbitrary orthogonal pairs of elliptic states of polarization. The principal states of polarization have different group delays, whose difference is referred to as "differential group delay", DGD below. If an optical signal is transmitted with one principal state of polarization, then, to a first-order approximation, no pulse widening takes place. If it is transmitted with a polarization which, in the case of splitting according to the two principal states of polarization, corresponds to power components that are identical there, maximum pulse widening occurs because two pulses of identical strength, with delay differences equal to DGD, are superposed. If the principal states of polarization change as a function of the optical frequency, then it is the case, however, that, when a principal state of polarization which corresponds to a specific frequency is used on the input side, the output state of polarization will nevertheless change as a function of the frequency, but actually only in a higher order than the first order. This is referred to as higher-order PMD. Higher-order PMD generally occurs, although first-order PMD is predominant due to its effects and, therefore, must be compensated preferentially. This is aggravated by the fact that the transmission response of the link, and hence the PMD too, changes as a result of temperature change or mechanical stress. Therefore, use is made of adaptive PMD compensators which are inserted in the transmission path. To drive these compensators, PMD distortions must be detected in the optical receiver. The compensator can then be set optimally using a gradient algorithm, for example.

In Electronic Letters, February 17, 1994, Volume 30, no. 4, pages 348 to 349, use is made of a bandpass filter for filtering a data signal whose PMD is to be detected. A power detector at the filter output supplies a signal which is higher, the smaller the PMD distortions are. In Electron. Lett. 34(1998) 23, pages 2258 to 2259, use is made of a combination of a number of bandpass filters with downstream power detectors, in which case, instead of individual signals, it is also possible to use a linear combination of the signals. By using bandpass filters having different center frequencies, it becomes possible, at the same time, to detect even relatively large PMD distortions which exceed, e.g., a bit duration of the signal. However, bandpass filters are poorly suited to monolithic integration; for example, in Si or SiGe. Moreover, unavoidable group delay distortions in the bandpass filters have the result that optimal PMD detection and hence equalization is not possible.

In Proceedings OEC 94, 14e-12, pages 258 to 259, Makuhari Trade Fair, Japan 1994, a different method is used, in which the power of the differential signal between decision-circuit output and decision-circuit input is evaluated. Incorrect decisions may occur, however, particularly in the event of severe PMD distortions in which the DGD exceeds the bit duration, so that the signal obtained in such cases is an unsuitable criterion for the presence of PMD distortions.

An object of the present invention, therefore, is to specify a reliable detector even for relatively large values of the differential group delay which can be integrated in a simple manner and, unlike bandpass filters, is not subject to intrinsic distortions through group delay distortions.

SUMMARY OF THE INVENTION

According to the present invention, use is made of EXCLUSIVE-OR gates (EXOR) or multipliers, which are used to determine essential parts of the autocorrelation function of the baseband signal present in the electrical part of an optical receiver. A particular advantage of the present invention is that EXOR gates can be monolithically integrated in a simple manner.

With EXOR gates which are separated by delay lines, the autocorrelation function values are produced for different time delays.

In an advantageous exemplary embodiment, two delay lines that are to be traversed in opposite directions are used, which can be implemented in a particularly space-saving manner and, moreover, at least approximately compensate the line losses.

Additional features and advantages of the present invention are described in, and will be apparent from, the following Detailed Description of the Invention and the Figures.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 shows a device according to the present invention for PMD detection, supplemented by PMD compensator and further assemblies.

Figure 2 shows a poor and a good sampled autocorrelation function.

Figure 3 shows a further exemplary embodiment of a device for PMD detection.

Figure 4 shows a variant of delay lines.

Figure 5 shows a further variant of a delay line.

Figure 6 shows a regenerator connected to a regulator.

DETAILED DESCRIPTION OF THE FIGURES

Figure 1 shows a system for optical PMD compensation having an optical input IN and an optical output OUT. An optical wave OS, coming from the input IN, traverses firstly an adjustable optical PMD compensator PMDC and then a power divider LT. One output of the power divider forms the optical output OUT of the system and the other drives a photodiode PD. After electrical amplification in amplifier V, the baseband signal BB is fed to an electrical power divider LTE.

The outputs of the electrical power divider are fed to two tapped delay lines LZ1, LZ2. The ends of the delay lines are provided with terminating resistors R1, R2 in accordance with the characteristic impedance. A tap A1j ($j = 1 \ldots n$) of the line LZ1 is respectively fed to one input and a tap A2j ($j = 1 \ldots n$) of the line LZ2 is respectively fed to the other input of an EXOR gate EXj ($j = 1 \ldots n$).

Instead of EXOR gates, any other multiplier circuits are also suitable. Gilbert multipliers are particularly suitable as EXOR gates/multipliers. A suitable circuit, in this case with field-effect transistors, is presented, for example, in

Electronics Letters, August 15, 1991, Volume 27, no. 17, pages 1529 to 1532, to be precise in Fig. 3 therein.

The taps are arranged according to a rising index j on one of the lines (LZ1) and according to a falling index j on the other line (LZ2). The result of this is that the delay difference between the signals at the inputs of an EXOR gate EXj changes monotonically with rising index j. If the line lengths between all the adjacent taps of a respective line are equal, then equidistant delay differences which change monotonically in accordance with index j are produced. Low-pass filters LPj ($j = 1 \ldots n$) are respectively connected to the outputs of the EXOR gates EXj. Instead of low-pass filters, other circuits which can be used for averaging, such as integrators, for example, which integrate over a defined time duration, are also suitable. These are also referred to as "Integrate-and-Dump" circuits. The output signals of the low-pass filters specify the values of the autocorrelation function of the electrical signal BB which are measured for different delay differences.

In order to compensate the losses at the taps A1j, A2j, to suppress multiple reflections on the delay lines LZ1, LZ2 and to obtain a longer signal delay for given dimensions, buffer amplifiers V1j, V2j ($j = 1 \ldots n$) may be inserted into the delay lines LZ1, LZ2. However, they are not absolutely necessary.

Since balanced circuitry with differential inputs and push-pull outputs affords numerous advantages, it is favorable to use it here, too. By way of example, amplifier V, power divider LTE, delay lines LZ1, LZ2, buffer amplifiers V1k, V2k, taps A1j, A2j, terminating resistors R1, R2, EXOR gates EXj and low-pass filters LPj may be of balanced design. The last-mentioned literature reference describes how this is done for, e.g., an EXOR gate.

EXOR gates EXj and at least parts of the delay lines LZ1, LZ2 including taps A1j, A2j and terminating resistors R1, R2 and, if present, buffer amplifiers V1k, V2k form an autocorrelation unit AKE. The latter may, for example, also include the remainder of the delay lines LZ1, LZ2, the electrical power divider LTE and the amplifier V. An autocorrelation unit AKE1 can be monolithically integrated in a space-saving manner on a semiconductor chip; e.g., in SiGe, GaAs or InP.

In practice, the taps give rise to losses on the delay lines LZ1, LZ2. However, since the input signals of all the EXOR gates traverse, in total, the same number of taps, i.e. upon addition of the traversed taps on line LZ1 and the traversed taps on LZ2, and, given a suitable design, also traverse line portions that are of the same length, in total, the product of the attenuation factors which these input signals experience is constant. This is true even in the absence of buffer amplifiers V1k, V2k. This advantageously has the result that the output signals of the different EXOR gates EXj correspond, with at least approximately the same proportionality factor, proportionally to the value of the autocorrelation function which corresponds to the respective delay.

In the exemplary embodiment of Figure 1, the signal delays between the outputs of the electrical power divider LTE and the taps A11 and A21 respectively, shall be identical. In this way, the value AKF1 of the autocorrelation function of the baseband signal BB for delay zero is produced at the output of the low-pass filter LP1. Between adjacent tap points A1k and A1(k+1) (k = 1 ... n-1) the signal delays shall be identical and have the value DT1. Between respectively adjacent tap points A2(k+1) and A2k (k = 1 ... n-1), the signal delays shall be identical and have the value DT2. Since the delay lines LZ1, LZ2 are traversed in opposite directions in the region of the EXOR gates, the value AKF2, AKF3, ... AKFn of the autocorrelation function of the baseband signal BB for delays DT, 2*DT, ..., (n-1)*DT, where DT = DT1+DT2, is respectively produced at the outputs of the remaining low-pass filters LP2 ... LPn. In order to minimize the chip area, it is advantageous to choose DT1 = DT2. It is furthermore favorable to choose DT to be equal to or shorter than a symbol duration T of the baseband signal BB. In the case of the binary signals usually used, a symbol duration T is equal to a bit duration. Since the autocorrelation function of a real signal has even symmetry, it is possible to dispense with the measurement of the values of the autocorrelation function with opposite delays. The maximum delay (n-1)*DT should, if possible, be at least equal to the sum of a differential group delay, caused by PMD, of the optical transmission link and the differential group delay generated by the PMD compensator PMDC.

The outputs of the low-pass filters LBj are fed to a regulator R. An autocorrelation function AKF sampled by values AKF1 ... AKFn is thus present here. If PMD is present and is not equalized, the value AKF1 is often smaller than the maximum possible value and the values AKF2 ... AKFn differ from zero even when they correspond to delays DT ... (n-1)*DT greater than a symbol duration T of the baseband signal. Such a poor autocorrelation function AKFBAD is shown by Figure 2. Only half of the autocorrelation function is shown since, after all, the autocorrelation function is symmetrical, so that measurement of the other half is unnecessary.

The regulator R adjusts the control signals SPMDC of the PMD compensator PMDC in such a way that the autocorrelation function is at least approximately equal to the autocorrelation function of the undistorted baseband signal. In the case of NRZ signals, this is a triangular pulse centered about delay zero, which pulse reaches the value zero for a delay of one bit duration T and remains there for longer delays. Such a good autocorrelation function AKFGOOD is also shown by Figure 2. In this case, the value AKF1 is maximal and the values AKF2 ... AKFn are at least approximately equal to zero when the delays DT ... (n-1)*DT are at least as long as a symbol duration T of the baseband signal. This applies to the values 2*DT ... (n-1)*DT in Figure 2. PMD is ideally equalized in this case. An ideally equalized optical signal therefore appears at the optical output OUT.

The optical power divider LT can also be omitted, so that the PMD compensator PMDC is directly connected to the photodiode PD on the output side. In this case, the electrical power divider LTE, as shown in Figure 1, should have a further electrical output LTEOR. An electrical data regenerator (often called 3R regenerator) REG is connected to the electrical output LTEOR. A regenerated data signal which at least approximately has no bit errors through PMD is available at the output OD of the regenerator.

Figure 3 shows a further exemplary embodiment of the device for PMD detection. Only the autocorrelation unit AKE of Figure 1 and a power divider LTE are shown here. In Figure 3, the signal flow directions of the delay lines LZ1, LZ2

along the EXOR gates are not opposite, as in Figure 1, but rather unidirectional. This can be seen also from the opposite positioning of the terminating resistor R2 and the opposite orientation of the buffer amplifiers V2j. As in Figure 1, buffer amplifiers are not absolutely necessary, or may be provided, e.g., only at some points.

In Figure 3, time delay DT1 shall be defined in the same way as in Figure 1. Between respectively adjacent tap points A2k and A2(k+1) (k = 1 ... n-1) of Figure 3, the signal delays shall be identical and have the value DT3. The delay differences between the inputs of successive correlators are therefore 0, DT, 2*DT ... (n-1)*DT where DT in this case has the value DT = DT1 - DT3. In order to obtain different DT1, DT3, detour lines Um (m = 2 ... n) are provided.

Instead of tapped delay lines LZ1, LZ2, it is also possible to use a number of delay lines LZ1j, LZ2j (j = 1 ... n) of different lengths. To that end, the power divider LTE must have a corresponding number of outputs. A suitable exemplary embodiment where n=4 is sketched in Figure 4. The delay lines LZ1j, LZ2j end at those points A1j, A2j which are connected to the EXOR gate inputs and were the tap points in Figures 1 and 2. The delay differences between the point pairs (A11, A21), (A12, A22), (A13, A23), (A14, A24) are 0, DT, 2*DT and 3*DT, respectively, where DT = DT1 + DT2.

Figure 5 illustrates part of an exemplary embodiment with only one delay line LZ1. The points A1j, which are connected to one EXOR gate input in each case, are strung along the delay line LZ1. The points A2j, which are connected to the other EXOR gate input in each case, all coincide and are identical to the point A11. Delay differences 0, DT, 2*DT ... (n-1)*DT between the EXOR gate inputs are obtained in this way.

In order to achieve an optimally low bit error rate, it is expedient for a measure of this bit error rate to be made available to the regulator R. This is possible in a simple manner if an electrical regenerator REG is provided. It may, therefore, be expedient to provide a regenerator REG even in cases where power divider LT and optical output OUT of the equalized optical signal are present. Figure 6 illustrates the regenerator REG. Clock recovery is generally necessary but

is not illustrated here for reasons of clarity. The regenerated data signal DS appears at the output OD, which is also the output of a D flip-flop DFF, to which the baseband signal BB is fed on the input side. The baseband signal is likewise fed to a second decision circuit (D flip-flop) DFF2. In this exemplary embodiment, the threshold of the decision circuit can be adjusted via a setting device EG to such an extent that the decision circuit already yields a data auxiliary signal DH affected by errors when the first decision circuit DFF still outputs an essentially error-free data signal DS. The output signals are compared with one another in an EXCLUSIVE-OR gate EXOR, and the error signal FS thus obtained is likewise fed to the regulator R for controlling the PMD compensator PMDC. A measure of how good the signal quality is with regard to a bit error rate that can be achieved is continuously developed by shifting the threshold of the second decision circuit via a setting device EG, which is controlled by the regulator R via a control signal ST2. The lower the error rate of the data auxiliary signal when the threshold is shifted from the optimum, the better the signal quality. Roughly, a maximum value of the autocorrelation function AKF1 for delay zero and zero values of the autocorrelation function for delays which are longer than a symbol duration T will also produce a minimum bit error rate. By contrast, a more accurate assessment which leads to a lower bit error rate of the decision circuit DFF is produced when the error signal FS is used. Since deviations of the data auxiliary signal DH from the data signal DS occur stochastically, however, a relatively long measurement or averaging time of the error signal FS is necessary in order to obtain a particularly good signal/noise ratio and, hence, optimal compensation. The additional information obtained with the aid of the second decision circuit is used to adaptively modify the regulating algorithm of the regulator R, which performs the setting of the PMD compensator PMDC with the aid of autocorrelation function measured values AKF1, AKF2, ... AKFn. By way of example, a slightly negative value AKF3 might be more favorable than the value zero. This adaptive form of operation appears to be particularly favorable for making manufacturing tolerances, temperature fluctuations, occurrence of nonlinear effects, etc., tolerable. The major advantage of these embodiments is that, through the measured values of the autocorrelation

function, rapid PMD compensation is already possible and sufficient time is available for the fine setting and the setting of the transfer function of the filter.

However, it is also possible to use only an error signal FS, particularly in cases where fast setting of the PMD compensator PMDC is not important. In this case, electrical power divider LTE and autocorrelation unit AKE and low-pass filters LPj may be omitted.

Although the present invention has been described with reference to specific embodiments, those of skill in the art will recognize that changes may be made thereto without departing from the spirit and scope of the invention as set forth in the hereafter appended claims.

ABSTRACT OF THE DISCLOSURE

Device for detecting polarization mode dispersion of an optical data signal, which has at least one EXOR gate together with an averaging device for measuring at least one value of the autocorrelation function of a baseband signal distorted by polarization mode dispersion.

In the claims:

On page 12, cancel line 1, and substitute the following left-hand justified heading therefor:

CLAIMS

Please cancel claims 1-13, without prejudice, and substitute the following claims therefor:

14. A device for detecting polarization mode dispersion of an optical data signal by evaluating an electrical baseband signal, comprising:

at least one multiplier which calculates a value of an autocorrelation function of the baseband signal by multiplication of a value of the baseband signal by a delayable value of the baseband signal; and

an averaging device for averaging the calculated value of the autocorrelation function.

15. A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 14, further comprising:

a delay line with taps, wherein taps with different delays are respectively connected to inputs of the at least one multiplier.

16. A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 15, wherein two delay lines are provided through which, in a region in which the two delay lines exhibit a mutual assignment via the inputs of the at least one multiplier, the baseband signal runs in opposite directions such that the delays occurring between adjacent multipliers are added to form a delay difference between the adjacent multipliers.

17. A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 15, wherein two delay lines are provided which, in a region in which the two delay lines exhibit an assignment via the inputs of the at least one multiplier, are traversed in a same direction such that the delays occurring

between adjacent multipliers are subtracted from one another to form a delay difference between the adjacent multipliers.

18. A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 14, further comprising:

a plurality of delay lines of different lengths to whose ends inputs of multipliers are connected.

19. A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 15, further comprising:

a detour line provided in one of the delay lines.

20. A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 15, further comprising:

a buffer amplifier in one of the delay lines.

21. A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 15, wherein delays that occur are equidistant with a constant delay difference.

22. A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 15, wherein a delay difference is at least approximately equal to a symbol duration of the baseband signal.

23. A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 14, further comprising:

a regulator for controlling a PMD compensator.

24. A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 23, wherein the regulator at least approximately maximizes a non-delayed value of the autocorrelation function and adjusts values

of the autocorrelation function that are delayed by at least one symbol duration at least approximately to the value zero.

25. A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 14, further comprising:

a measuring arrangement for measuring a bit error rate in the event of one of an intentionally impaired reception signal and a changed threshold value of a second decision stage, an error signal of the measuring arrangement controlling a PMD compensator via a regulator.

26. A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 25, wherein the regulator is used additionally for adaptively setting the values of the autocorrelation function that are sought.

27. A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 14, wherein the multiplier is an EXOR gate.

28. A device for detecting polarization mode dispersion of an optical data signal as claimed in Claim 14, where the multiplier is a Gilbert multiplier.

REMARKS

The present amendment makes editorial changes and corrects typographical errors in the specification, which includes the Abstract, in order to conform the specification to the requirements of United States Patent Practice. No new matter is added thereby. Attached hereto is a marked-up version of the changes made to the specification by the present amendment. The attached page is captioned **"Version With Markings To Show Changes Made".**

In addition, the present amendment cancels original claims 1-13 in favor of new claims 14-28. Claims 14-28 have been presented solely because the revisions by red-lining and underlining which would have been necessary in claims 1-13 in order to present those claims in accordance with preferred United States Patent Practice would have been too extensive, and thus would have been too burdensome. The present amendment is intended for clarification purposes only and not for substantial reasons related to patentability pursuant to 35 USC §§101, 102, 103 or 112. Indeed, the cancellation of claims 1-13 does not constitute an intent on the part of the Applicants to surrender any of the subject matter of claims 1-13.

Early consideration on the merits is respectfully requested.

Respectfully submitted,

(Reg. No. 39,056)

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VERSIONS WITH MARKINGS TO SHOW CHANGES MADE

~~Description~~

SPECIFICATION

~~Device for detecting polarization mode dispersion~~

TITLE OF THE INVENTION

DEVICE FOR DETECTING POLARIZATION MODE DISPERSION

~~The invention relates to a device for detecting polarization mode dispersion of an optical data signal in accordance with the preamble of patent claim 1.~~

BACKGROUND OF THE INVENTION

Long optical waveguide transmission links are used in optical transmission technology. Production dictates that the optical waveguides are not completely isotropic, but rather weakly birefringent. The long transmission link results in frequency-dependent polarization transformation~~-~~, called polarization mode dispersion or polarization dispersion, abbreviated to PMD. Through the change in the polarization of the optical signal as a function of the optical frequency and~~-~~, associated therewith~~-~~, different frequency-dependent delays, this PMD leads to the widening of transmitted pulses~~, which means that~~. As such, at the receiving end, the identifiability of ~~said~~ the pulses is reduced and, as a result, the transmitted data rate is limited. The term "principal states of polarization", referred to as PSP below, designates those two states of polarization which are orthogonal to one another and to a first approximation do not change when the optical frequency changes. In polarization-maintaining optical waveguides, the principal states of polarization coincide with the principal axes~~,~~; in other words, are horizontal and vertical. In general, however, the principal states of polarization are arbitrary orthogonal pairs of elliptic states of polarization. The principal states of polarization have different group delays, whose difference is referred to as "differential group delay", DGD below. If an optical signal is transmitted with one principal state of polarization, then, to a first-order approximation, no pulse widening takes place. If it is transmitted with a polarization which, in the case of splitting according to the two principal states of polarization, corresponds to power components that are identical there, maximum pulse widening occurs because two

pulses of identical strength, with delay differences equal to DGD, are superposed. If the principal states of polarization change as a function of the optical frequency, then it is the case, however, that, when a principal state of polarization which corresponds to a specific frequency is used on the input side, the output state of polarization will nevertheless change as a function of the frequency, but actually only in a higher order than the first order. This is referred to as higher-order PMD. Higher-order PMD generally occurs, although first-order PMD is predominant due to its effects and ~~must~~, therefore, must be compensated preferentially. This is aggravated by the fact that the transmission response of the link, and hence the PMD too, changes as a result of temperature change or mechanical stress. Therefore, use is made of adaptive PMD compensators which are inserted in the transmission path. To drive these compensators, PMD distortions must be detected in the optical receiver. The compensator can then be set optimally using a gradient algorithm, for example.

In Electronic Letters, February 17, 1994, Volume 30, no. 4, pages 348 to 349, use is made of a bandpass filter for filtering a data signal whose PMD is to be detected. A power detector at the filter output supplies a signal which is higher, the smaller the PMD distortions are. In Electron. Lett. 34(1998) 23, pages 2258 to 2259, use is made of a combination of a ~~plurality~~ number of bandpass filters with downstream power detectors, in which case, instead of individual signals, it is also possible to use a linear combination of the signals. By using bandpass filters having different center frequencies, it becomes possible, at the same time, to detect even relatively large PMD distortions which exceed, e.g., a bit duration of the signal. However, bandpass filters are poorly suited to monolithic integration~~,~~; for example, in Si or SiGe. Moreover, unavoidable group delay distortions in the bandpass filters have the result that optimal PMD detection and hence equalization is not possible.

In Proceedings OEC 94, 14e-12, pages 258 to 259, Makuhari Trade Fair, Japan 1994, a different method is used, in which the power of the differential signal between decision-circuit output and decision-circuit input is evaluated. Incorrect decisions may occur, however, particularly in the event of severe PMD distortions

in which the DGD exceeds the bit duration, so that the signal obtained in such cases is an unsuitable criterion for the presence of PMD distortions.

~~The~~ An object of the present invention, therefore, is to specify a reliable detector even for relatively large values of the differential group delay which can be integrated in a simple manner and, unlike bandpass filters, is not subject to intrinsic distortions through group delay distortions.

~~The object is achieved by means of a device for detecting polarization mode dispersion in accorance with claim 1.~~

SUMMARY OF THE INVENTION

~~Advantageous developments of the invention are specified in the subclaims.~~

~~According to the~~ According to the present invention, use is made of EXCLUSIVE-OR gates (EXOR) or multipliers, which are used to determine essential parts of the autocorrelation function of the baseband signal present in the electrical part of an optical receiver. ~~The~~ A particular advantage of the present invention is that EXOR gates can be monolithically integrated in a simple manner.

With EXOR gates which are separated by delay lines, the autocorrelation function values are produced for different time delays.

In an advantageous exemplary embodiment, two delay lines that are to be traversed in opposite directions are used, which can be implemented in a particularly space-saving manner and, moreover, at least approximately compensate the line losses.

~~Exemplary embodiments of the invention will be described with reference to figures.~~ Additional features and advantages of the present invention are described in, and will be apparent from, the following Detailed Description of the Invention and the Figures.

~~In the figures:~~ BRIEF DESCRIPTION OF THE FIGURES

Figure 1 shows a device according to the present invention for PMD detection, supplemented by PMD compensator and further assemblies~~,~~.

Figure 2 shows a poor and a good sampled autocorrelation function~~,~~.

Figure 3 shows a further exemplary embodiment of a device for PMD detection~~,~~.

Figure 4 shows a variant of delay lines~~,~~.

Figure 5 shows a further variant of a delay line~~, and~~.

Figure 6 shows a regenerator connected to a regulator.

DETAILED DESCRIPTION OF THE FIGURES

Figure 1 shows a system for optical PMD compensation~~. It has~~ having an optical input IN and an optical output OUT. An optical wave OS, coming from the input IN, traverses firstly an adjustable optical PMD compensator PMDC and then a power divider LT. One output of the power divider forms the optical output OUT of the system and the other drives a photodiode PD. After electrical amplification in amplifier V, the baseband signal BB is fed to an electrical power divider LTE.

The outputs of the electrical power divider are fed to two tapped delay lines LZ1, LZ2. The ends of the delay lines are provided with terminating resistors R1, R2 in accordance with the characteristic impedance. A tap A1j (j = 1 ... n) of the line LZ1 is respectively fed to one input and a tap A2j (j = 1 ... n) of the line LZ2 is respectively fed to the other input of an EXOR gate EXj (j = 1 ... n).

Instead of EXOR gates, any other multiplier circuits are also suitable. Gilbert multipliers are particularly suitable as EXOR gates/multipliers. A suitable circuit, in this case with field-effect transistors, is presented, for example, in Electronics Letters, August 15, 1991, Volume 27, no. 17, pages 1529 to 1532, to be precise in Fig. 3 therein.

The taps are arranged according to a rising index j on one of the lines (LZ1) and according to a falling index j on the other line (LZ2). The result of this is that the delay difference between the signals at the inputs of an EXOR gate EXj changes monotonically with rising index j. If the line lengths between all the adjacent taps of a respective line are equal, then equidistant delay differences which change monotonically in accordance with index j are produced. Low-pass filters LPj (j = 1 ... n) are respectively connected to the outputs of the EXOR gates EXj. Instead of low-pass filters, other circuits which can be used for averaging, such as integrators, for example, which integrate over a defined time duration, are also suitable. These are also referred to as "Integrate-and-Dump" circuits. The output

signals of the low-pass filters specify the values of the autocorrelation function of the electrical signal BB which are measured for different delay differences.

In order to compensate the losses at the taps A1j, A2j, to suppress multiple reflections on the delay lines LZ1, LZ2 and to obtain a longer signal delay for given dimensions, buffer amplifiers V1j, V2j (j = 1 ... n) may be inserted into the delay lines LZ1, LZ2. However, they are not absolutely necessary.

Since balanced circuitry with differential inputs and push-pull outputs affords numerous advantages, it is favorable to use it here, too. By way of example, amplifier V, power divider LTE, delay lines LZ1, LZ2, buffer amplifiers V1k, V2k, taps A1j, A2j, terminating resistors R1, R2, EXOR gates EXj and low-pass filters LPj may be of balanced design. The last-mentioned literature reference describes how this is done ~~for~~, e.g., for an EXOR gate.

EXOR gates EXj and at least parts of the delay lines LZ1, LZ2 including taps A1j, A2j and terminating resistors R1, R2 and, if present, buffer amplifiers V1k, V2k form an autocorrelation unit AKE. The latter may, for example, also ~~comprise~~ include the remainder of the delay lines LZ1, LZ2, the electrical power divider LTE and the amplifier V. An autocorrelation unit AKE1 can be monolithically integrated in a space-saving manner on a semiconductor chip~~,~~; e.g., in SiGe, GaAs or InP.

In practice, the taps give rise to losses on the delay lines LZ1, LZ2. However, since the input signals of all the EXOR gates traverse, in total, the same number of taps, i.e. upon addition of the traversed taps on line LZ1 and the traversed taps on LZ2, and, given a suitable design, also traverse line portions that are of the same length, in total, the product of the attenuation factors which these input signals experience is constant. This is true even in the absence of buffer amplifiers V1k, V2k. This advantageously has the result that the output signals of the different EXOR gates EXj correspond, with at least approximately the same proportionality factor, proportionally to the value of the autocorrelation function which corresponds to the respective delay.

In the exemplary embodiment of Figure 1, the signal delays between the outputs of the electrical power divider LTE and the taps A11 and A21 respectively,

shall be identical. In this way, the value AKF1 of the autocorrelation function of the baseband signal BB for delay zero is produced at the output of the low-pass filter LP1. Between adjacent tap points A1k and A1(k+1) (k = 1 ... n-1) the signal delays shall be identical and have the value DT1. Between respectively adjacent tap points A2(k+1) and A2k (k = 1 ... n-1), the signal delays shall be identical and have the value DT2. Since the delay lines LZ1, LZ2 are traversed in opposite directions in the region of the EXOR gates, the value AKF2, AKF3, ... AKFn of the autocorrelation function of the baseband signal BB for delays DT, 2*DT, ..., (n-1)*DT, where DT = DT1+DT2, is respectively produced at the outputs of the remaining low-pass filters LP2 ... LPn. In order to minimize the chip area, it is advantageous to choose DT1 = DT2. It is furthermore favorable to choose DT to be equal to or shorter than a symbol duration T of the baseband signal BB. In the case of the binary signals usually used, a symbol duration T is equal to a bit duration. Since the autocorrelation function of a real signal has even symmetry, it is possible to dispense with the measurement of the values of the autocorrelation function with opposite delays. The maximum delay (n-1)*DT should, if possible, be at least equal to the sum of a differential group delay-, caused by PMD-, of the optical transmission link and the differential group delay generated by the PMD compensator PMDC.

The outputs of the low-pass filters LBj are fed to a regulator R. An autocorrelation function AKF sampled by values AKF1 ... AKFn is thus present here. If PMD is present and is not equalized, the value AKF1 is often smaller than the maximum possible value and the values AKF2 ... AKFn differ from zero even when they correspond to delays DT ... (n-1)*DT greater than a symbol duration T of the baseband signal. Such a poor autocorrelation function AKFBAD is shown by Figure 2. Only half of the autocorrelation function is shown since, after all, ~~said~~ the autocorrelation function is symmetrical, so that measurement of the other half is unnecessary.

The regulator R adjusts the control signals SPMDC of the PMD compensator PMDC in such a way that the autocorrelation function is at least approximately equal to the autocorrelation function of the undistorted baseband

signal. In the case of NRZ signals, this is a triangular pulse centered about delay zero, which pulse reaches the value zero for a delay of one bit duration T and remains there for longer delays. Such a good autocorrelation function AKFGOOD is also shown by Figure 2. In this case, the value AKF1 is maximal and the values AKF2 ... AKFn are at least approximately equal to zero when the delays DT ... (n-1)*DT are at least as long as a symbol duration T of the baseband signal. This applies to the values 2*DT ... (n-1)*DT in Figure 2. PMD is ideally equalized in this case. An ideally equalized optical signal therefore appears at the optical output OUT.

The optical power divider LT can also be omitted, so that the PMD compensator PMDC is directly connected to the photodiode PD on the output side. In this case, the electrical power divider LTE, as shown in Figure 1, should have a further electrical output LTEOR. An electrical data regenerator (often called 3R regenerator) REG is connected to ~~said~~ the electrical output LTEOR. A regenerated data signal which at least approximately has no bit errors through PMD is available at the output OD of ~~said~~ the regenerator.

Figure 3 shows a further exemplary embodiment of the device for PMD detection. Only the autocorrelation unit AKE of Figure 1 and a power divider LTE are shown here. In Figure 3, the signal flow directions of the delay lines LZ1, LZ2 along the EXOR gates are not opposite, as in Figure 1, but rather unidirectional. This can ~~also~~ be seen also from the opposite positioning of the terminating resistor R2 and the opposite orientation of the buffer amplifiers V2j. As in Figure 1, buffer amplifiers are not absolutely necessary, or may be provided, e.g., only at some points.

In Figure 3, time delay DT1 shall be defined in the same way as in Figure 1. Between respectively adjacent tap points A2k and A2(k+1) (k = 1 ... n-1) of Figure 3, the signal delays shall be identical and have the value DT3. The delay differences between the inputs of successive correlators are therefore 0, DT, 2*DT ... (n-1)*DT where DT in this case has the value DT = DT1 - DT3. In order to obtain different DT1, DT3, detour lines Um (m = 2 ... n) are provided.

Instead of tapped delay lines LZ1, LZ2, it is also possible to use a ~~plurality~~ number of delay lines LZ1j, LZ2j (j = 1 ... n) of different lengths. To that end, the power divider LTE must have a corresponding number of outputs. A suitable exemplary embodiment where n=4 is sketched in Figure 4. The delay lines LZ1j, LZ2j end at those points A1j, A2j which are connected to the EXOR gate inputs and were the tap points in Figures 1 and 2. The delay differences between the point pairs (A11, A21), (A12, A22), (A13, A23), (A14, A24) are 0, DT, 2*DT and 3*DT, respectively, where DT = DT1 + DT2.

Figure 5 illustrates part of an exemplary embodiment with only one delay line LZ1. The points A1j, which are connected to one EXOR gate input in each case, are strung along the delay line LZ1. The points A2j, which are connected to the other EXOR gate input in each case, all coincide and are identical to the point A11. Delay differences 0, DT, 2*DT ... (n-1)*DT between the EXOR gate inputs are obtained in this way.

In order to achieve an optimally low bit error rate, it is expedient for a measure of this bit error rate to be made available to the regulator R. This is possible in a simple manner if an electrical regenerator REG is provided. It may, therefore, be expedient to provide a regenerator REG even in cases where power divider LT and optical output OUT of the equalized optical signal are present. Figure 6 illustrates the regenerator REG. Clock recovery is generally necessary but is not illustrated here for reasons of clarity. The regenerated data signal DS appears at the output OD, which is also the output of a D flip-flop DFF, to which the baseband signal BB is fed on the input side. The baseband signal is likewise fed to a second decision circuit (D flip-flop) DFF2.

In this exemplary embodiment, the threshold of the decision circuit can be adjusted via a setting device EG to such an extent that ~~said~~ the decision circuit already yields a data auxiliary signal DH affected by errors when the first decision circuit DFF still outputs an essentially error-free data signal DS. The output signals are compared with one another in an EXCLUSIVE-OR gate EXOR, and the error signal FS thus obtained is likewise fed to the regulator R for controlling the PMD compensator PMDC. A measure of how good the signal quality is with regard to a

bit error rate that can be achieved is continuously developed by shifting the threshold of the second decision circuit ~~by means of~~ via a setting device EG, which is controlled by the regulator R via a control signal ST2. The lower the error rate of the data auxiliary signal when the threshold is shifted from the optimum, the better the signal quality. Roughly, a maximum value of the autocorrelation function AKF1 for delay zero and zero values of the autocorrelation function for delays which are longer than a symbol duration T will also produce a minimum bit error rate. By contrast, a more accurate assessment which leads to a lower bit error rate of the decision circuit DFF is produced when the error signal FS is used. Since deviations of the data auxiliary signal DH from the data signal DS occur stochastically, however, a relatively long measurement or averaging time of the error signal FS is necessary in order to obtain a particularly good signal/noise ratio and, hence, optimal compensation. The additional information obtained with the aid of the second decision circuit is used to adaptively modify the regulating algorithm of the regulator R, which performs the setting of the PMD compensator PMDC with the aid of autocorrelation function measured values AKF1, AKF2, ... AKFn. By way of example, a slightly negative value AKF3 might be more favorable than the value zero. This adaptive form of operation appears to be particularly favorable for making manufacturing tolerances, temperature fluctuations, occurrence of nonlinear effects, etc., tolerable. The major advantage of these embodiments is that, through the measured values of the autocorrelation function, rapid PMD compensation is already possible and sufficient time is available for the fine setting and the setting of the transfer function of the filter.

However, it is also possible to use only an error signal FS, particularly in cases where fast setting of the PMD compensator PMDC is not important. In this case, electrical power divider LTE and autocorrelation unit AKE and low-pass filters LPj may be omitted.

Although the present invention has been described with reference to specific embodiments, those of skill in the art will recognize that changes may be made thereto without departing from the spirit and scope of the invention as set forth in the hereafter appended claims.

ABSTRACT OF THE DISCLOSURE ~~Abstract~~

~~Device for detecting polarization mode dispersion~~

Device for detecting polarization mode dispersion of an optical data signal~~(OS)~~, which has at least one EXOR gate ~~(EXj; j = 1 ... n)~~ together with an averaging device ~~(LPj; j = 1 ... n)~~ for measuring at least one value ~~(AKFj; j = 1 ... n)~~ of the autocorrelation function of a baseband signal ~~(BB)~~ distorted by polarization mode dispersion.

~~Figure 1~~

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Description

Device for detecting polarization mode dispersion

The invention relates to a device for detecting polarization mode dispersion of an optical data signal in accordance with the preamble of patent claim 1.

Long optical waveguide transmission links are used in optical transmission technology. Production dictates that the optical waveguides are not completely isotropic, but rather weakly birefringent. The long transmission link results in frequency-dependent polarization transformation - called polarization mode dispersion or polarization dispersion, abbreviated to PMD. Through the change in the polarization of the optical signal as a function of the optical frequency and - associated therewith - different frequency-dependent delays, this PMD leads to the widening of transmitted pulses, which means that, at the receiving end, the identifiability of said pulses is reduced and, as a result, the transmitted data rate is limited. The term "principal states of polarization", referred to as PSP below, designates those two states of polarization which are orthogonal to one another and to a first approximation do not change when the optical frequency changes. In polarization-maintaining optical waveguides, the principal states of polarization coincide with the principal axes, in other words are horizontal and vertical. In general, however, the principal states of polarization are arbitrary orthogonal pairs of elliptic states of polarization. The principal states of polarization have different group delays, whose difference is referred to as "differential group delay", DGD below. If an optical signal is transmitted with one principal state of polarization, then, to a first-order approximation, no pulse widening takes place. If it is transmitted with a

polarization which, in the case of splitting according to the two principal states of polarization, corresponds to power components that are identical there, maximum

pulse widening occurs because two pulses of identical strength, with delay differences equal to DGD, are superposed. If the principal states of polarization change as a function of the optical frequency, then it is the case, however, that, when a principal state of polarization which corresponds to a specific frequency is used on the input side, the output state of polarization will nevertheless change as a function of the frequency, but actually only in a higher order than the first order. This is referred to as higher-order PMD. Higher-order PMD generally occurs, although first-order PMD is predominant due to its effects and must therefore be compensated preferentially. This is aggravated by the fact that the transmission response of the link, and hence the PMD too, changes as a result of temperature change or mechanical stress. Therefore, use is made of adaptive PMD compensators which are inserted in the transmission path. To drive these compensators, PMD distortions must be detected in the optical receiver. The compensator can then be set optimally using a gradient algorithm, for example.

In Electronic Letters, February 17, 1994, Volume 30, no. 4, pages 348 to 349, use is made of a bandpass filter for filtering a data signal whose PMD is to be detected. A power detector at the filter output supplies a signal which is higher, the smaller the PMD distortions are. In Electron. Lett. 34(1998) 23, pages 2258 to 2259, use is made of a combination of a plurality of bandpass filters with downstream power detectors, in which case, instead of individual signals, it is also possible to use a linear combination of the signals. By using bandpass filters having different center frequencies, it becomes possible, at the same time, to detect even relatively large PMD distortions which exceed e.g. a bit duration of the signal. However, bandpass filters are poorly suited to monolithic integration, for example

in Si or SiGe. Moreover, unavoidable group delay distortions in the bandpass filters have the result that optimal PMD detection and hence equalization is not possible.

In Proceedings OEC 94, 14e-12, pages 258 to 259, Makuhari Trade Fair, Japan 1994, a different method is used, in which the power of the differential signal between decision-circuit output and decision-circuit input is evaluated. Incorrect decisions may occur, however, particularly in the event of severe PMD distortions in which the DGD exceeds the bit duration, so that the signal obtained in such cases is an unsuitable criterion for the presence of PMD distortions.

The object of the invention is to specify a reliable detector even for relatively large values of the differential group delay which can be integrated in a simple manner and, unlike bandpass filters, is not subject to intrinsic distortions through group delay distortions.

The object is achieved by means of a device for detecting polarization mode dispersion in accorance with claim 1.

Advantageous developments of the invention are specified in the subclaims.

According to the invention, use is made of EXCLUSIVE-OR gates (EXOR) or multipliers, which are used to determine essential parts of the autocorrelation function of the baseband signal present in the electrical part of an optical receiver. The particular advantage of the invention is that EXOR gates can be monolithically integrated in a simple manner.

With EXOR gates which are separated by delay lines, the autocorrelation function values are produced for different time delays.

In an advantageous exemplary embodiment, two delay lines that are to be traversed in opposite directions are

used, which can be implemented in a particularly space-saving manner and, moreover, at least approximately compensate the line losses.

Exemplary embodiments of the invention will be described with reference to figures.

In the figures:

Figure 1 shows a device according to the invention for PMD detection, supplemented by PMD compensator and further assemblies,

Figure 2 shows a poor and a good sampled autocorrelation function,

Figure 3 shows a further exemplary embodiment of a device for PMD detection,

Figure 4 shows a variant of delay lines,

Figure 5 shows a further variant of a delay line, and

Figure 6 shows a regenerator connected to a regulator.

Figure 1 shows a system for optical PMD compensation. It has an optical input IN and an optical output OUT. An optical wave OS, coming from the input IN, traverses firstly an adjustable optical PMD compensator PMDC and then a power divider LT. One output of the power divider forms the optical output OUT of the system and the other drives a photodiode PD. After electrical amplification in amplifier V, the baseband signal BB is fed to an electrical power divider LTE.

The outputs of the electrical power divider are fed to two tapped delay lines LZ1, LZ2. The ends of the delay lines are provided with terminating resistors R1, R2 in accordance with the characteristic impedance. A tap A1j (j = 1 ... n) of the line LZ1 is respectively fed to one input and a tap A2j (j = 1 ... n) of the line LZ2 is respectively fed to the other input of an EXOR gate EXj (j = 1 ... n).

Instead of EXOR gates, any other multiplier circuits are also suitable. Gilbert multipliers are particularly suitable as EXOR gates/multipliers. A suitable circuit, in this case with field-effect transistors, is presented for example in Electronics Letters, August 15, 1991, Volume 27, no. 17, pages 1529 to 1532, to be precise in Fig. 3 therein.

The taps are arranged according to a rising index j on one of the lines (LZ1) and according to a falling index j on the other line (LZ2). The result of this is that the delay difference between the signals at the inputs of an EXOR gate EXj changes monotonically with rising index j. If the line lengths between all the adjacent taps of a respective line are equal, then equidistant delay differences which change monotonically in accordance with index j are produced. Low-pass filters LPj (j = 1 ... n) are respectively connected to the outputs of the EXOR gates EXj. Instead of low-pass filters, other circuits which can be used for averaging, such as integrators, for example, which integrate over a defined time duration, are also suitable. These are also referred to as "Integrate-and-Dump" circuits. The output signals of the low-pass filters specify the values of the autocorrelation function of the electrical signal BB which are measured for different delay differences.

In order to compensate the losses at the taps A1j, A2j, to suppress multiple reflections on the delay lines LZ1, LZ2 and to obtain a longer signal delay for given dimensions, buffer amplifiers V1j, V2j (j = 1 ... n) may be inserted into the delay lines LZ1, LZ2. However, they are not absolutely necessary.

Since balanced circuitry with differential inputs and push-pull outputs affords numerous advantages, it is favorable to use it here, too. By way of example,

amplifier V, power divider LTE, delay lines LZ1, LZ2, buffer amplifiers V1k, V2k, taps A1j, A2j,

terminating resistors R1, R2, EXOR gates EXj and low-pass filters LPj may be of balanced design. The last-mentioned literature reference describes how this is done for e.g. an EXOR gate.

EXOR gates EXj and at least parts of the delay lines LZ1, LZ2 including taps A1j, A2j and terminating resistors R1, R2 and, if present, buffer amplifiers V1k, V2k form an autocorrelation unit AKE. The latter may, for example, also comprise the remainder of the delay lines LZ1, LZ2, the electrical power divider LTE and the amplifier V. An autocorrelation unit AKE1 can be monolithically integrated in a space-saving manner on a semiconductor chip, e.g. in SiGe, GaAs or InP.

In practice, the taps give rise to losses on the delay lines LZ1, LZ2. However, since the input signals of all the EXOR gates traverse, in total, the same number of taps, i.e. upon addition of the traversed taps on line LZ1 and the traversed taps on LZ2, and, given a suitable design, also traverse line portions that are of the same length, in total, the product of the attenuation factors which these input signals experience is constant. This is true even in the absence of buffer amplifiers V1k, V2k. This advantageously has the result that the output signals of the different EXOR gates EXj correspond, with at least approximately the same proportionality factor, proportionally to the value of the autocorrelation function which corresponds to the respective delay.

In the exemplary embodiment of Figure 1 the signal delays between the outputs of the electrical power divider LTE and the taps A11 and A21 respectively, shall be identical. In this way, the value AKF1 of the autocorrelation function of the baseband signal BB for delay zero is produced at the output of the low-pass

filter LP1. Between adjacent tap points A1k and A1(k+1) (k = 1 ... n-1) the signal delays shall be identical

and have the value DT1. Between respectively adjacent tap points A2(k+1) and A2k (k = 1 ... n-1), the signal delays shall be identical and have the value DT2. Since the delay lines LZ1, LZ2 are traversed in opposite directions in the region of the EXOR gates, the value AKF2, AKF3, ... AKFn of the autocorrelation function of the baseband signal BB for delays DT, 2*DT, ..., (n-1)*DT, where DT = DT1+DT2, is respectively produced at the outputs of the remaining low-pass filters LP2 ... LPn. In order to minimize the chip area, it is advantageous to choose DT1 = DT2. It is furthermore favorable to choose DT to be equal to or shorter than a symbol duration T of the baseband signal BB. In the case of the binary signals usually used, a symbol duration T is equal to a bit duration. Since the autocorrelation function of a real signal has even symmetry, it is possible to dispense with the measurement of the values of the autocorrelation function with opposite delays. The maximum delay (n-1)*DT should, if possible, be at least equal to the sum of a differential group delay - caused by PMD - of the optical transmission link and the differential group delay generated by the PMD compensator PMDC.

The outputs of the low-pass filters LBj are fed to a regulator R. An autocorrelation function AKF sampled by values AKF1 ... AKFn is thus present here. If PMD is present and is not equalized, the value AKF1 is often smaller than the maximum possible value and the values AKF2 ... AKFn differ from zero even when they correspond to delays DT ... (n-1)*DT greater than a symbol duration T of the baseband signal. Such a poor autocorrelation function AKFBAD is shown by **Figure 2**. Only half of the autocorrelation function is shown since, after all, said autocorrelation function is symmetrical, so that measurement of the other half is unnecessary.

The regulator R adjusts the control signals SPMDC of the PMD compensator PMDC in such a way that the autocorrelation function

is at least approximately equal to the autocorrelation function of the undistorted baseband signal. In the case of NRZ signals, this is a triangular pulse centered about delay zero, which pulse reaches the value zero for a delay of one bit duration T and remains there for longer delays. Such a good autocorrelation function AKFGOOD is also shown by Figure 2. In this case, the value AKF1 is maximal and the values AKF2 ... AKFn are at least approximately equal to zero when the delays DT ... (n-1)*DT are at least as long as a symbol duration T of the baseband signal. This applies to the values 2*DT ... (n-1)*DT in Figure 2. PMD is ideally equalized in this case. An ideally equalized optical signal therefore appears at the optical output OUT.

The optical power divider LT can also be omitted, so that the PMD compensator PMDC is directly connected to the photodiode PD on the output side. In this case, the electrical power divider LTE, as shown in Figure 1, should have a further electrical output LTEOR. An electrical data regenerator (often called 3R regenerator) REG is connected to said electrical output LTEOR. A regenerated data signal which at least approximately has no bit errors through PMD is available at the output OD of said regenerator.

Figure 3 shows a further exemplary embodiment of the device for PMD detection. Only the autocorrelation unit AKE of Figure 1 and a power divider LTE are shown here. In Figure 3, the signal flow directions of the delay lines LZ1, LZ2 along the EXOR gates are not opposite, as in Figure 1, but rather unidirectional. This can also be seen from the opposite positioning of the terminating resistor R2 and the opposite orientation of the buffer amplifiers V2j. As in Figure 1, buffer amplifiers are not absolutely necessary, or may be provided e.g. only at some points.

In Figure 3, time delay DT1 shall be defined in the same way as in Figure 1. Between respectively adjacent tap points A2k and A2(k+1) (k = 1 ... n-1) of Figure 3, the signal delays shall be identical and have the value DT3. The delay differences between the inputs of successive correlators are therefore 0, DT, 2*DT ... (n-1)*DT where DT in this case has the value DT = DT1 - DT3. In order to obtain different DT1, DT3, detour lines Um (m = 2 ... n) are provided.

Instead of tapped delay lines LZ1, LZ2, it is also possible to use a plurality of delay lines LZ1j, LZ2j (j = 1 ... n) of different lengths. To that end, the power divider LTE must have a corresponding number of outputs. A suitable exemplary embodiment where n=4 is sketched in **Figure 4**. The delay lines LZ1j, LZ2j end at those points A1j, A2j which are connected to the EXOR gate inputs and were the tap points in Figures 1 and 2. The delay differences between the point pairs (A11, A21), (A12, A22), (A13, A23), (A14, A24) are 0, DT, 2*DT and 3*DT, respectively, where DT = DT1 + DT2.

Figure 5 illustrates part of an exemplary embodiment with only one delay line LZ1. The points A1j, which are connected to one EXOR gate input in each case, are strung along the delay line LZ1. The points A2j, which are connected to the other EXOR gate input in each case, all coincide and are identical to the point A11. Delay differences 0, DT, 2*DT ... (n-1)*DT between the EXOR gate inputs are obtained in this way.

In order to achieve an optimally low bit error rate, it is expedient for a measure of this bit error rate to be made available to the regulator R. This is possible in a simple manner if an electrical regenerator REG is provided. It may therefore be expedient to provide a regenerator REG even in cases where power divider LT

and optical output OUT of the equalized optical signal are present. **Figure 6**

illustrates the regenerator REG. Clock recovery is generally necessary but is not illustrated here for reasons of clarity. The regenerated data signal DS appears at the output OD, which is also the output of a D flip-flop DFF, to which the baseband signal BB is fed on the input side. The baseband signal is likewise fed to a second decision circuit (D flip-flop) DFF2.

In this exemplary embodiment, the threshold of the decision circuit can be adjusted via a setting device EG to such an extent that said decision circuit already yields a data auxiliary signal DH affected by errors when the first decision circuit DFF still outputs an essentially error-free data signal DS. The output signals are compared with one another in an EXCLUSIVE-OR gate EXOR, and the error signal FS thus obtained is likewise fed to the regulator R for controlling the PMD compensator PMDC. A measure of how good the signal quality is with regard to a bit error rate that can be achieved is continuously developed by shifting the threshold of the second decision circuit by means of a setting device EG, which is controlled by the regulator R via a control signal ST2. The lower the error rate of the data auxiliary signal when the threshold is shifted from the optimum, the better the signal quality. Roughly, a maximum value of the autocorrelation function AKF1 for delay zero and zero values of the autocorrelation function for delays which are longer than a symbol duration T will also produce a minimum bit error rate. By contrast, a more accurate assessment which leads to a lower bit error rate of the decision circuit DFF is produced when the error signal FS is used. Since deviations of the data auxiliary signal DH from the data signal DS occur stochastically, however, a relatively long measurement or averaging time of the error signal FS is necessary in order to obtain a particularly good signal/noise ratio and hence optimal compensation. The additional information obtained with the aid of the second decision circuit is used to

adaptively modify the regulating algorithm of the regulator R, which performs the setting of the PMD compensator PMDC with the aid of autocorrelation

function measured values AKF1, AKF2, ... AKFn. By way of example, a slightly negative value AKF3 might be more favorable than the value zero. This adaptive form of operation appears to be particularly favorable for making manufacturing tolerances, temperature fluctuations, occurrence of nonlinear effects etc. tolerable. The major advantage of these embodiments is that, through the measured values of the autocorrelation function, rapid PMD compensation is already possible and sufficient time is available for the fine setting and the setting of the transfer function of the filter.

However, it is also possible to use only an error signal FS, particularly in cases where fast setting of the PMD compensator PMDC is not important. In this case, electrical power divider LTE and autocorrelation unit AKE and low-pass filters LPj may be omitted.

Patent claims

1. A device for detecting polarization mode dispersion of an optical data signal (OS) by evaluating an electrical baseband signal (BB), characterized in that at least one multiplier (EXj; j = 1 ... n) is provided, which calculates a value (AKFj; j = 1 ... n) of the autocorrelation function (AKF) of the baseband signal (BB) by multiplication of a value of the baseband signal (BB) by a delayable value of the baseband signal and subsequent averaging in an averaging device (LPj; j = 1 ... n).

2. The device as claimed in claim 1, characterized in that a delay line (LZ1, LZ2) with taps (A1j, A2j; j = 1 ... n) is provided, in that taps (A1j and A2j) with different delays (0, DT, 2*DT, ... (n-1,*DT) are respectively connected to the inputs of a multiplier (EXj).

3. The device as claimed in claim 2, characterized in that two delay lines (LZ1, LZ2) are provided, through which, in the region in which they exhibit a mutual assignment via the inputs of multipliers (EXj), said baseband signal (BB) runs in opposite directions, so that the delays (DT1, DT2) occurring between adjacent multipliers (EXk and EX(k+1); k = 1 ... n-1) are added to form a delay difference (DT = DT1 + DT2) between said multipliers.

4. The device as claimed in claim 2, characterized

in that two delay lines (LZ1, LZ2) are provided, which, in the region in which they exhibit an assignment via the inputs of multipliers

(EXj), are traversed in the same direction, so that the delays (DT1, DT3) occurring between adjacent multipliers (EXk and EX(k+1); k = 1 ... n-1) are subtracted from one another to form a delay difference (DT = DT1 - DT3) between said multipliers.

5. The device as claimed in claim 1, characterized in that a plurality of delay lines (LZ1j, LZ2j; j = 1 ... n) of different lengths are provided, to whose ends (A1j, A2j; j = 1 ... n) the inputs of multipliers (EXj) are connected.

6. The device as claimed in one of claims 2 to 5, characterized in that a detour line (Um; m = 2 ... n) or a buffer amplifier (V1j, V2j; j = 1 ... n) is provided in a delay line (LZ1, LZ2, LZ1j, LZ2j; j = 1 ... n).

7. The device as claimed in one of claims 2 to 6, characterized in that delays (0, DT, 2*DT, ... (n-1)*DT) that occur are equidistant with a constant delay difference (DT).

8. The device as claimed in one of claims 2 to 7, characterized in that a delay difference (DT) is at least approximately equal to a symbol duration (T) of the baseband signal (BB).

9. The device as claimed in one of the preceding claims, characterized in that provision is made of a regulator (R) for controlling a PMD compensator (PMDC).

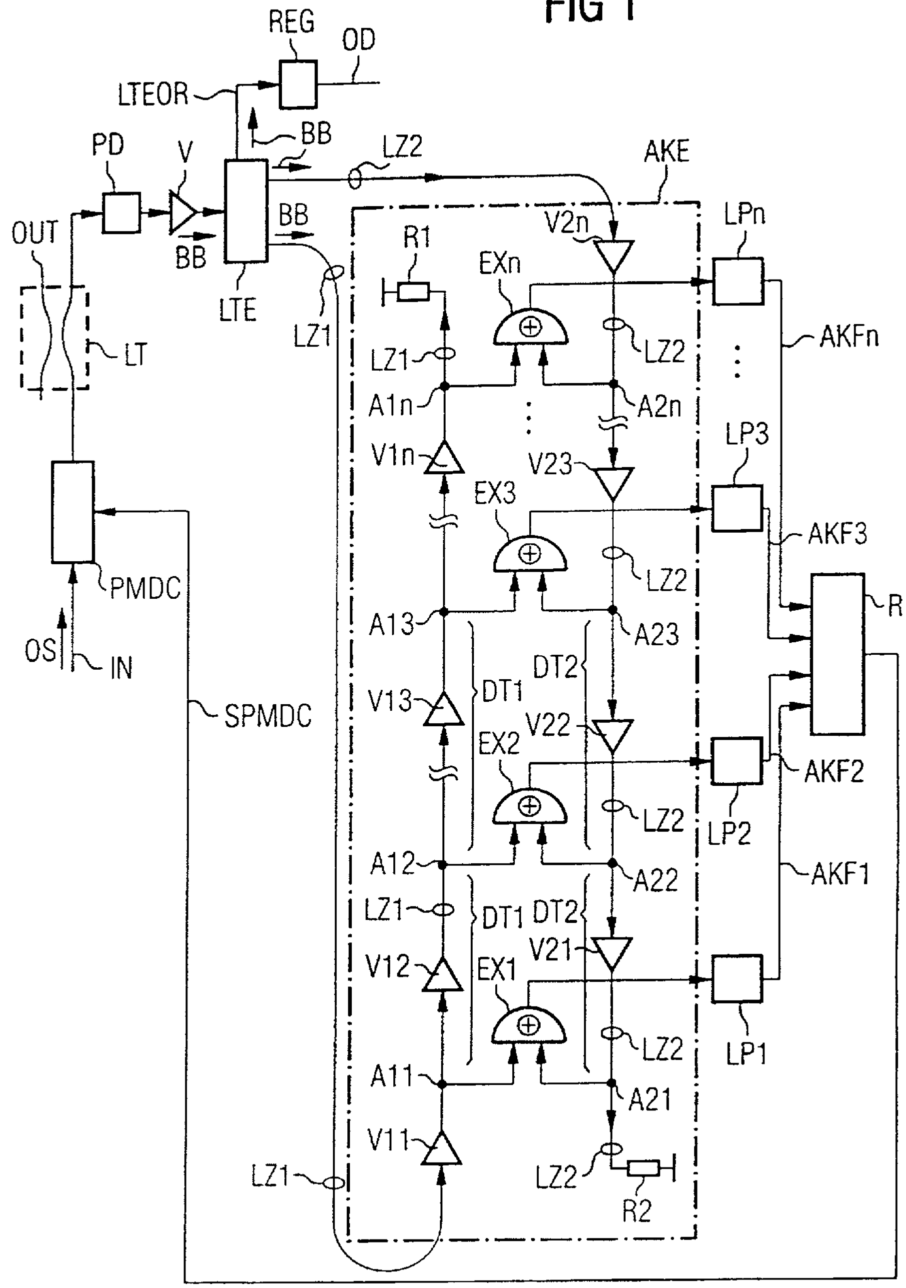
10. The device as claimed in claim 9, characterized in that the regulator (R) at least approximately maximizes a non-delayed value (AKF1) of the autocorrelation function and adjusts values (AKF2, AKF3 ... AKFn) of the autocorrelation function that are delayed by at least one symbol duration (T) at least approximately to the value zero.

11. The device as claimed in one of the preceding claims, characterized in that provision is made of a measuring arrangement (EG; DFF2; EXOR) for measuring the bit error rate in the event of an intentionally impaired reception signal or a changed threshold value of a second decision stage (DFF2), whose error signal (FS) controls a PMD compensator (PMDC) via a regulator (R).

12. The device as claimed in claim 11, characterized in that the regulator (R) is used additionally for adaptively setting the values of the autocorrelation function (AKFj; j = 1 ... n) that are to be sought.

13. The device as claimed in one of the preceding claims, characterized in that the multiplier (EXj) is an EXOR gate or a Gilbert multiplier

FIG 1


REG
OD
LTEOR
BB
LZ2
AKE
PD
V
OUT
BB
LTE
LZ1
LT
R1
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V2n
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AKFn
LZ1
A1n
LZ2
A2n
V1n
V23
LP3
EX3
AKF3
PMDC
LZ2
R
A13
A23
DT2
OS
IN
DT1
SPMDC
V13
V22
EX2
AKF2
LZ2
LP2
A12
A22
LZ1
DT1
DT2
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LZ2
R2

FIG 2

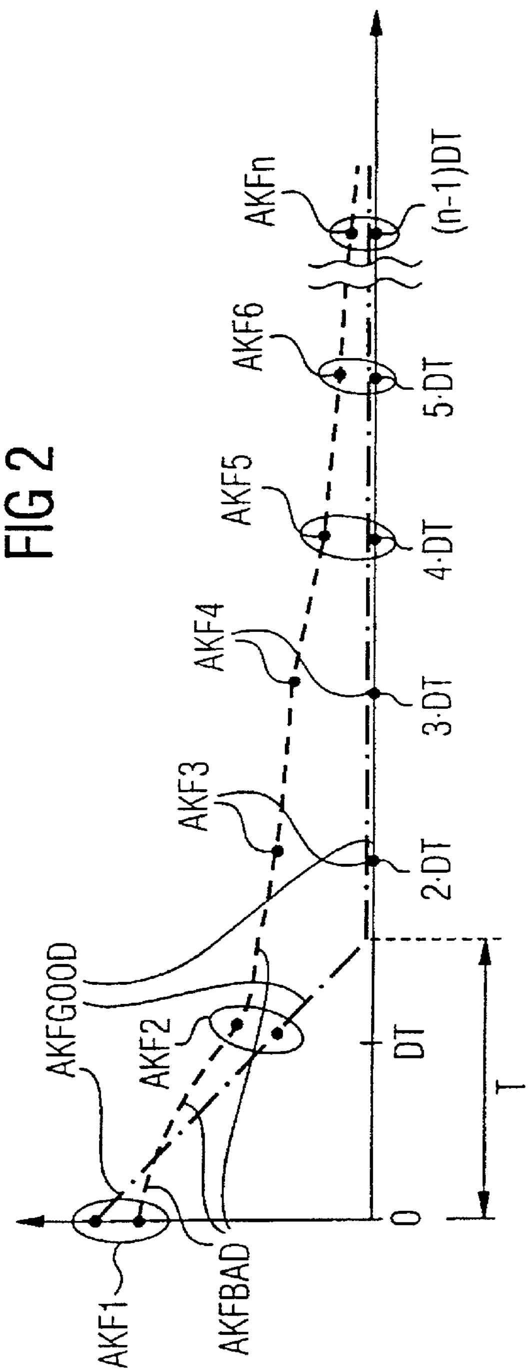

AKF1
AKFBAD
AKFGOOD
AKF2
AKF3
AKF4
AKF5
AKF6
AKFn
0
DT
2·DT
3·DT
4·DT
5·DT
(n-1)DT
T

FIG 3

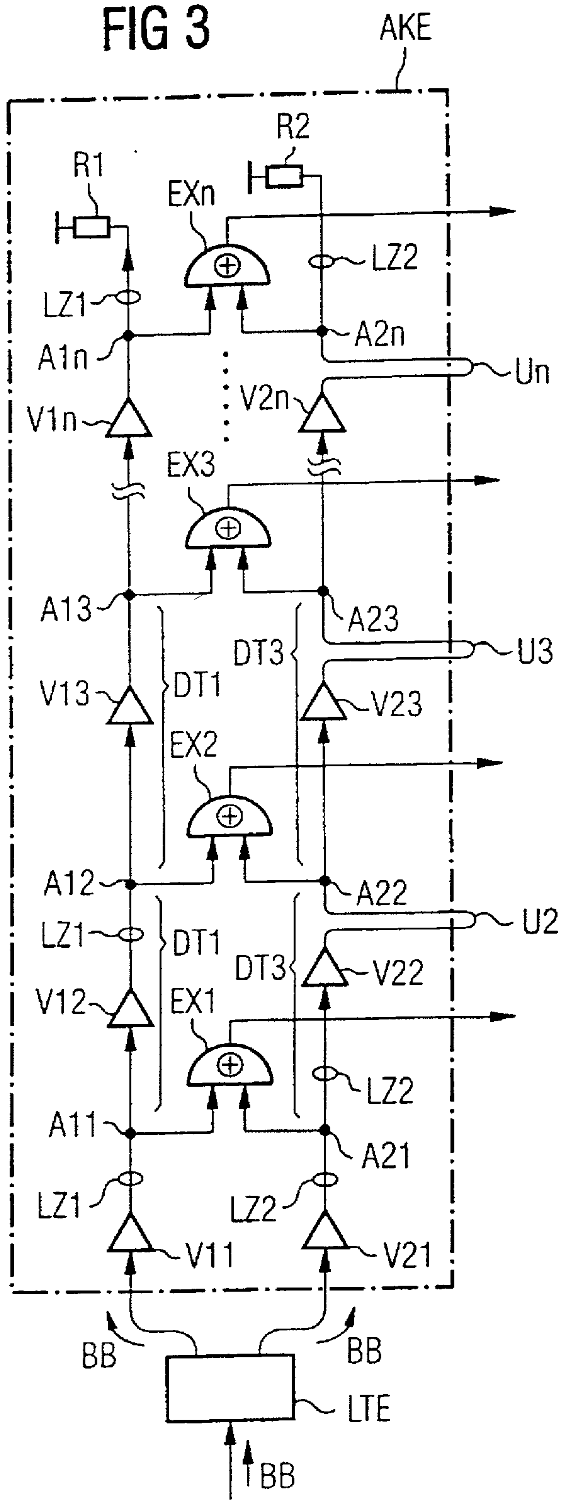

AKE
R1
R2
EXn
LZ2
LZ1
A1n
A2n
Un
V1n
V2n
EX3
A13
A23
DT3
U3
V13
DT1
V23
EX2
A12
A22
U2
LZ1
DT1
DT3
V22
V12
EX1
LZ2
A11
A21
LZ1
LZ2
V11
V21
BB
BB
LTE
BB

FIG 4

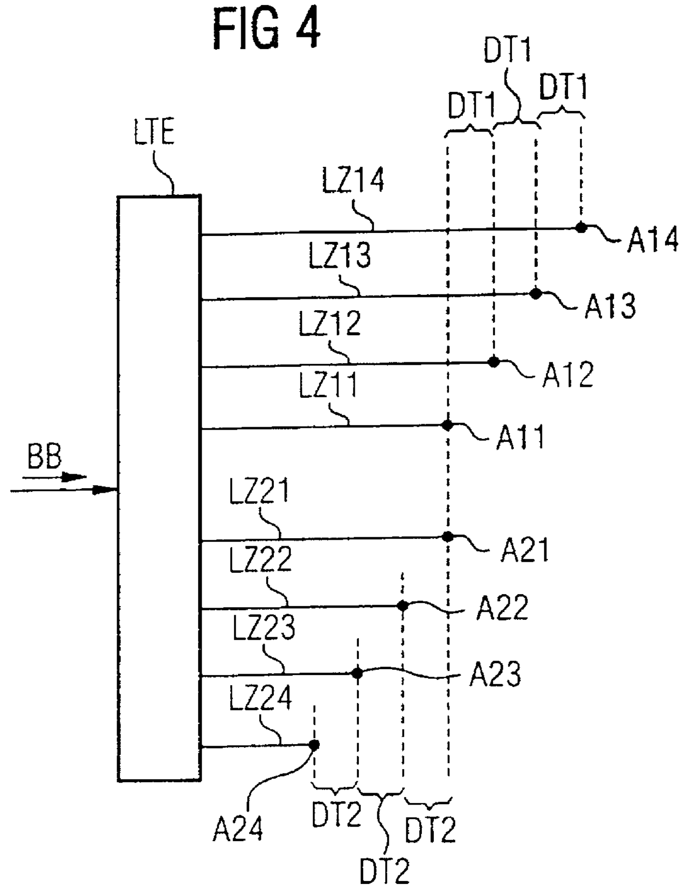

DT1
DT1
DT1
LTE
LZ14
A14
LZ13
A13
LZ12
A12
LZ11
A11
BB
LZ21
A21
LZ22
A22
LZ23
A23
LZ24
A24
DT2
DT2
DT2

FIG 5

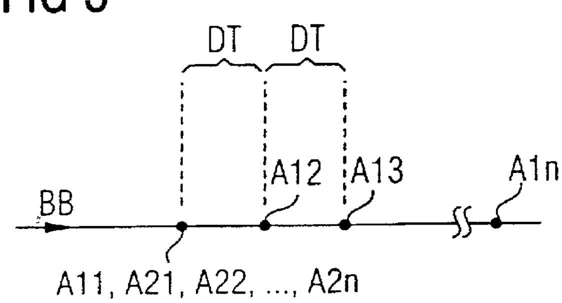
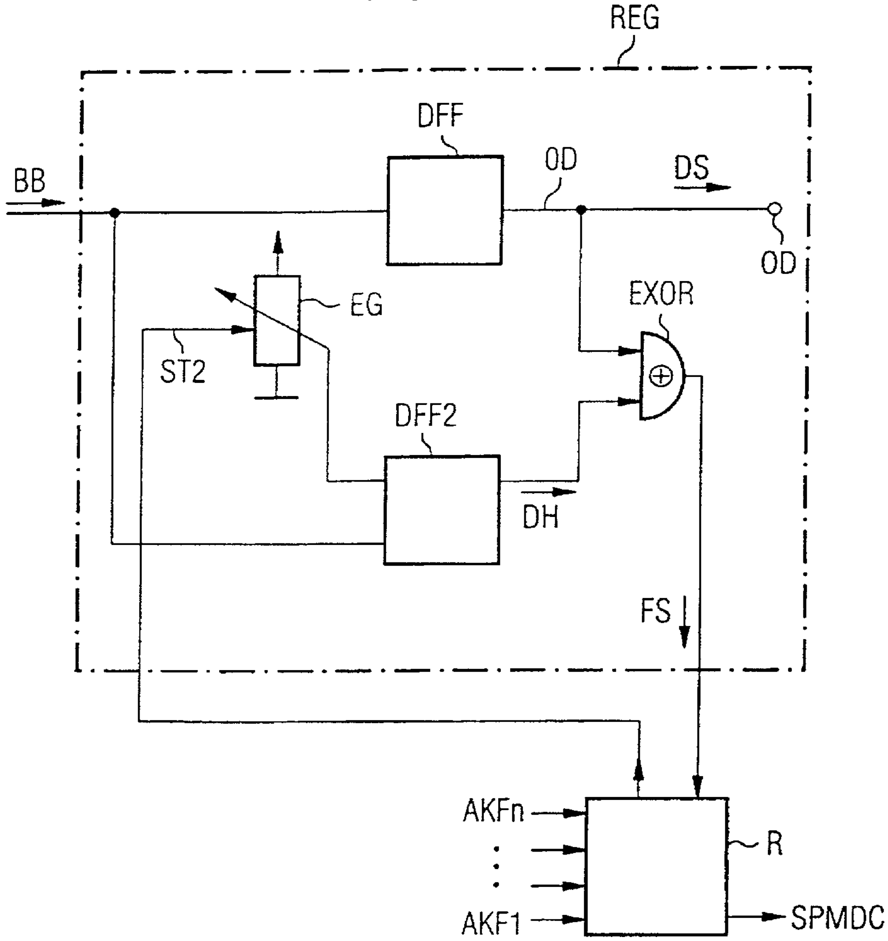

DT
DT
A12
A13
A1n
BB
A11, A21, A22, ..., A2n

FIG 6



Declaration and Power of Attorney For Patent Application
Erklärung Für Patentanmeldungen Mit Vollmacht
German Language Declaration

Als nachstehend benannter Erfinder erkläre ich hiermit an Eides Statt:

As a below named inventor, I hereby declare that:

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My residence, post office address and citizenship are as stated below next to my name,

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I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

Einrichtung zur Detektion von Polarisationsmodendispersion

Device for detecting polarization mode dispersions

deren Beschreibung

(zutreffendes ankreuzen)
☐ hier beigefügt ist.
☒ am 14.04.2000 als
PCT internationale Anmeldung
PCT Anmeldungsnummer PCT/DE00/01175
eingereicht wurde und am ______
abgeändert wurde (falls tatsächlich abgeändert).

the specification of which

(check one)
☐ is attached hereto.
☒ was filed on 14.04.2000 as
PCT international application
PCT Application No. PCT/DE00/01175
and was amended on ______
(if applicable)

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I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims as amended by any amendment referred to above.

Ich erkenne meine Pflicht zur Offenbarung irgendwelcher Informationen, die für die Prüfung der vorliegenden Anmeldung in Einklang mit Absatz 37, Bundesgesetzbuch, Paragraph 1.56(a) von Wichtigkeit sind, an.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a).

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I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

German Language Declaration

Prior foreign appplications
Priorität beansprucht

			Priority Claimed	
19929673.1 (Number) (Nummer)	DE (Country) (Land)	28.06.1999 (Day Month Year Filed) (Tag Monat Jahr eingereicht)	☒ Yes Ja	☐ No Nein
(Number) (Nummer)	(Country) (Land)	(Day Month Year Filed) (Tag Monat Jahr eingereicht)	☐ Yes Ja	☐ No Nein
(Number) (Nummer)	(Country) (Land)	(Day Month Year Filed) (Tag Monat Jahr eingereicht)	☐ Yes Ja	☐ No Nein

Ich beanspruche hiermit gemäss Absatz 35 der Zivilprozessordnung der Vereinigten Staaten, Paragraph 120, den Vorzug aller unten aufgeführten Anmeldungen und falls der Gegenstand aus jedem Anspruch dieser Anmeldung nicht in einer früheren amerikanischen Patentanmeldung laut dem ersten Paragraphen des Absatzes 35 der Zivilprozeßordnung der Vereinigten Staaten, Paragraph 122 offenbart ist, erkenne ich gemäss Absatz 37, Bundesgesetzbuch, Paragraph 1.56(a) meine Pflicht zur Offenbarung von Informationen an, die zwischen dem Anmeldedatum der früheren Anmeldung und dem nationalen oder PCT internationalen Anmeldedatum dieser Anmeldung bekannt geworden sind.

I hereby claim the benefit under Title 35. United States Code. §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §122, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occured between the filing date of the prior application and the national or PCT international filing date of this application.

PCT/DE00/01175 (Application Serial No.) (Anmeldeseriennummer)	14.04.2000 (Filing Date D, M, Y) (Anmeldedatum T, M, J)	anhängig (Status) (patentiert, anhängig, aufgegeben)	pending (Status) (patented, pending, abandoned)
(Application Serial No.) (Anmeldeseriennummer)	(Filing Date D,M,Y) (Anmeldedatum T, M; J)	(Status) (patentiert, anhängig, aufgeben)	(Status) (patented, pending, abandoned)

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German Language Declaration

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Voller Name des einzigen oder ursprünglichen Erfinders: Prof. REINHOLD NOE	Full name of sole or first inventor: Prof. REINHOLD NOE
Unterschrift des Erfinders Reinhold Noé Datum 28.11.2001	Inventor's signature Date
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Staatsangehörigkeit AT	Citizenship AT
Postanschrift HELMERNER WEG 2	Post Office Address HELMERNER WEG 2
33100 PADERBORN	33100 PADERBORN
Voller Name des zweiten Miterfinders (falls zutreffend):	Full name of second joint inventor, if any:
Unterschrift des Erfinders Datum	Second Inventor's signature Date
Wohnsitz ,	Residence ,
Staatsangehörigkeit	Citizenship
Postanschrift	Post Office Address

(Bitte entsprechende Informationen und Unterschriften im Falle von dritten und weiteren Miterfindern angeben).

(Supply similar information and signature for third and subsequent joint inventors).

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